Lifetime Performance of an Energy Efficient Clustering Algorithm for Cluster-Based Wireless Sensor Networks

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Abstract. This paper proposes a fixed clustering algorithm (FCA) to improve energy efficiency for wireless sensor networks (WSNs). In order to reduce the consuming energy of sending data at each sensor, the proposed algorithm uniformly divides the sensing area into clusters where the cluster head is deployed in the center of the cluster area. Simulation results show that the proposed algorithm definitely reduces the energy consumption of the sensors and extends the lifetime of the networks nearly more 80% compared to the random clustering (RC).

1 Introduction

Recently, the rapidly developed technologies of microelectro-mechanical systems and telecommunication battery make the small sensors comprise the capabilities of wireless communication and data processing [1]. These small sensors could be used as the surveillance and the control capability under a certain environment. Specially, the location of wireless sensor network (WSN) could be a region where people could not easily reach and there is a difficulty to recharge the device energy. Therefore, the energy efficiency of the sensor networks is an important research topic and the lifetime of WSNs could be considered as the most significant performance in the WSN [2]. Moreover, there are two main issues in the lifetime prolong problems. One is to minimize the energy dissipation for all energy constrained nodes. The other one is to balance the energy dissipation of all nodes [2].

The energy in WSN is mainly consuming on the direct data transmission [2]. Firstly, each sensor collects data and delivers the data to the base station directly, called as “sink”. Applying this mode, the sensor will have quick energy exhaustion if

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it is apart from the base station. Thus, this kind transmission scheme is not suitable in a large area [2]. Then, secondly, to enable communication between sensors not within each other's communication range, the common multi-hop routing protocol is applied in the ad hoc wireless sensors communication networks [3]-[5]. In this scheme, several multi-hop paths exist to perform the network connectivity. Each path in the configuration will have one link head to collects data from sensors.

Every sensor node in the WSN sends both the sensing data of itself and the receiving data from previous nodes to its closer node. Then, the destination node delivers the data collection in the path to the base station [4]. The nodes closer to the base station need more energy [4] to send data because the scheme uses hierarchy transmission. However, due the highly complexity in routing protocols and the most likely heavy load on the relaying nodes, this scheme is not suitable for the highly densely WSNs.

The third scheme is the cluster-based one that those closer sensors belong to their own clusters. One of sensors, called "cluster head," in each cluster is responsible for delivering data back to the base station. In this scheme, the cluster head performs data compressing and sending back to the base station. Thus, the lifetime of cluster head may be shorter than that of other sensors [5-7]. Therefore, for WSNs with a large number of energy-constrained sensors, it is very important to design an algorithm to organize sensors in clusters to minimize the energy used to communicate information from all nodes to the base station. Moreover, if the cluster head has more energy, the cluster can prolong the life time. Therefore, in this paper, we would like to propose a fast, centralized algorithm for organizing the sensors in a wireless sensor network into clusters with an objective of minimizing the energy dissipated in communicating the information to the cluster head and prolong the lifetime of the WSN. Furthermore, the energy efficiency of heterogeneous networks with different amount energy at the normal sensors and cluster heads is investigated in this paper.

2 Network Models

In practical, the geometry of the WSN is non-regular. However, the square is a basic area to be consisted of non-regular area. Thus, for simplification, in this paper we adopt a square area with the length D. The sensor area is with a uniformly distributed cluster heads and is shown in Fig. 1. In Fig. 1, the symbol "+" is represented as a location of cluster head whereas the symbol "o" is represented as a location of the sensing node. When the cluster area is of random distributed, the energy efficiency of sensor nodes on data transmitting is terrible [3]. Therefore, the FCA is proposed to divide the sensor area into clusters and to deploy cluster heads uniformly over the network area. Based on the configuration of square area, the sensors are supposed to be spread out uniformly to the whole area. The data from each cluster will be collected by the cluster head and these data will be sent back to the base station located at the point (0, -B).

In wireless communication, the channel models are modeled by

$$P_r = c\frac{P_t}{d^{\alpha}}, \tag{1}$$

where P_r and P_t are the received power at receiver and the transmitted power at transmitter respectively, c is the propagation coefficient, and α is the path loss exponent, $2 \leq \alpha < 6$. For s free space area, the path loss exponent is set by $\alpha = 2$. The location of the nodes is assumed to be known to base station by GPS.

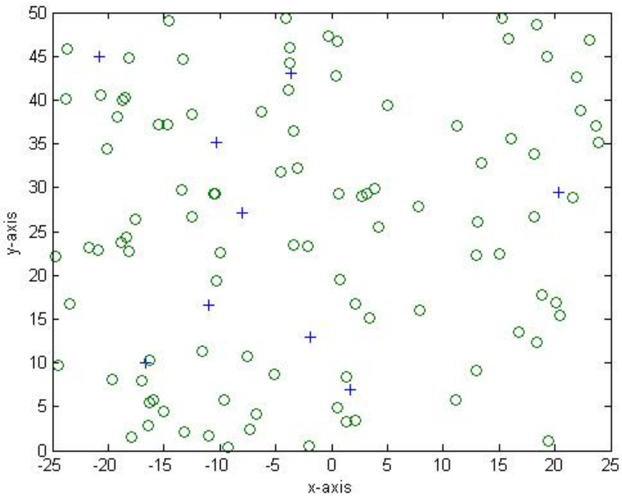

Fig. 1. Random clustering deployment sensor network

In Mac layer, the sensing nodes are assumed to know the belonging cluster head by centralized based station broadcasting. Based on the configuration of square area, Fig. 1 shows the investigated environment in this paper. In Fig. 1, the total Q sensors are supposed to be spread out uniformly to the whole area where is divided into q clusters. The data from each cluster will be collected by the cluster head and these data will be sent back to the base station located at the point (0, -B).

To evaluate the lifetime of the network, one round is defined as a cycle in which the base station receives data from the sensor node. In one round, it contains the time from the data collected at sensor to the corresponding cluster head and the time from the cluster head to the base station.

Thus, the total energy of networks in one round can be expressed by

$$E_T = \sum_{i=1}^{q} \left(\eta_i \cdot E_{ch,i} \cdot \frac{Q}{q} \right) + \sum_{j=1}^{Q-q} E_{n,j} \tag{2}$$

where η_i is a data compressing factor for the ith cluster with $0 < \eta_i < 1$, $E_{ch,i}$ and $E_{n,j}$ are the transmission energy of one packet for the ith cluster head and the jth normal sensor, respectively. Moreover, the dissipation energy of nodes depends on the path loss.

3 Fixed Clustering Algorithm

In order to minimize the energy dissipation of the sensor nodes, an FCA is proposed to normalize the clustering region. The defined parameters for the FCA are depicted in Table 1. There is a cluster head located at the area centric of each clustering area. In order to divide the area into uniform clusters in size, we calculate the location of the cluster head according to the number of clusters q as shown in Fig. 2. In Fig. 2, $x(i)$ and $y(i)$ are the axis of corresponding position of the cluster head. Then, the fixed cluster sensor network can be deployed by FCA. The proposed FCA is described as followings.

Table 1. Definition of variables in FCA

Variable	Description
q	Number of clusters
D	Length of sensing area
p	$\sqrt{q}$
n	$\lceil p \rceil$
k	$\mathrm{mod}\left(\frac{q}{n}\right)$
s	$\left\lfloor \frac{q}{n} \right\rfloor$
l	$\frac{D_1(n-1)}{q}$

Class A: When the number of clusters equals to $p\times p$, that is, the clusters in row and those in column are the same. For example, when the number of clusters is equal to 9, the positions of the cluster heads exhibit a square matrix form by three-row and three-column.

Class B: Depending on the parameter k, if $k = 0$, the clustering is performed by Class B. Otherwise, Class C will be applied in the clustering. In Class B, the number of clusters are with 1×2, 2×3, 3×4, 4×5, ..., $M\times(M+1)$, $M\in\mathbf{N}$. The axes of cluster heads are obtained as shown in Fig. 2 by applying class B.

Class C: When the number of clusters does not fit in Class A or B, then the clustering algorithm is classified to class C. In Class C, we first compare the values between s and $(n-1)$. Then, there are two sub-classes C1 and C2 for the conditions $s<n$-1 and $s\geq n$-1, respectively, as shown in Fig. 2.

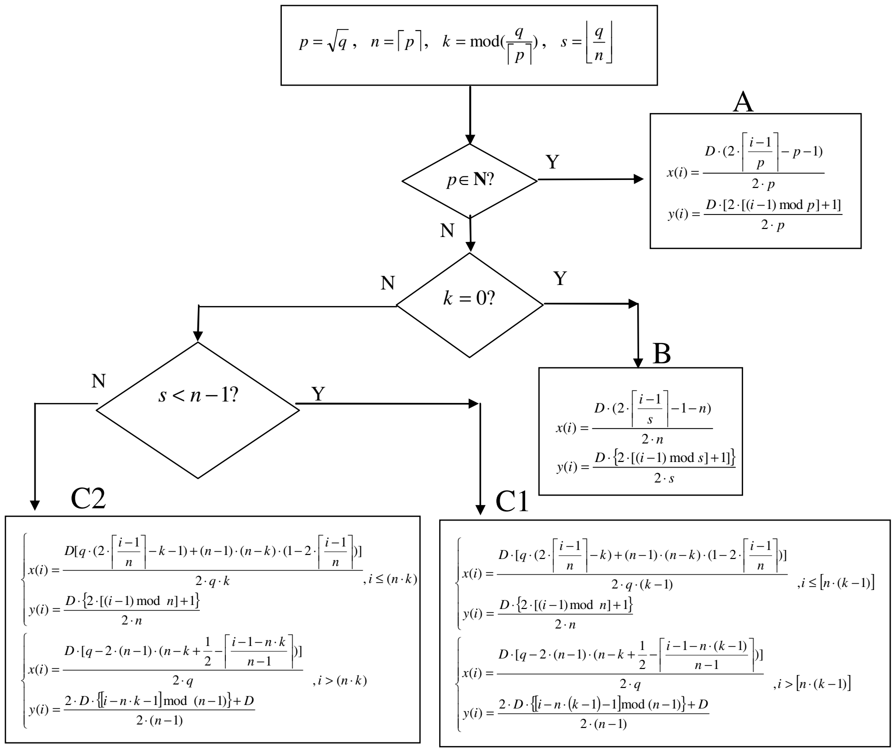

Fig. 2. The flow chart of proposed FCA for a square sensing area

In FCA, we assume that the sensor nodes are uniformly distributed in the area of the cluster. Therefore, the power dissipation of a cluster head to relay the information of the cluster in one round can be obtained by

$$E_{ch,i} = \eta_i \cdot e_l \cdot W_i \cdot \frac{Q}{q}, \tag{3}$$

where e_l is the energy dissipation sending one packet per square meters, the energy dissipation due to the path loss of a distance between the ith cluster head and the base station is expressed by

$$W_i = d_i^{\alpha}/c = d_i^2 = x^2(i)+[y(i)+B]^2, \tag{4}$$

where a = 2 and c = 1. Moreover, the energy dissipation for a sensor node to transmit one packet in a clustering area can be obtained by

$$E_{n,j} = e_l \cdot Z_j, \tag{5}$$

where $Z_j = d_j^2$ is the random variable of the rectangular square of the distance between the jth normal sensor node and the cluster head of the cluster.

Thus, the expected power dissipation for a sensor node to transmit one packet in a rectangular clustering area can be obtained by

$$E[Z] = E\left[(x-\frac{L_1}{2})^2 + (y-\frac{L_2}{2})^2\right] = \frac{1}{12}\left(L_1{}^2 + L_2{}^2\right), \tag{6}$$

where L_1 and L_2 are the width and length of the rectangular area of the cluster in which the cluster head is located at ($L_1/2$, $L_2/2$).

In the RC, the cluster head is selected randomly. Therefore, the energy dissipation of each cluster in transmitting one packet is expressed by

$$E[Z] = E[x^2 + (y+B)^2] = \frac{5D^2}{12} + B \cdot D + B^2 , \tag{7}$$

where D is the length of the square and B is the distance between the sensing field and the base station. Therefore, by the number of clusters we can choose the suitable algorithm to equally cluster the cluster area.

4 Simulation Results and Discussions

In order to verify and compare the energy efficiency of the proposed FCA, a simulation work is presented. In the simulation, we assumed that the energy dissipation sending one packet by each sensor is e_l=5×10^{-7} Joule (J)/m^2. In our simulation, the total number of sensors nodes is one hundred, Q=100. Then, the normal sensor nodes are 100-q. The length of sensing square area is set D=50 meters. The base station is deployed at (0, -B)=(0, -10). To be generalization, the worst case in data fusion with data compressing factors for all clusters η_i=1 is performed in the simulations.

Firstly, we compare the energy efficiency between the performance of the proposed FCA and the random clustering (RC) in which the cluster heads are randomly selected to perform clustering [3]. The performance of RC had been analyzed in [3]. Fig. 3 shows the energy consumption of one round vs. the number of clusters. It depicts that the consuming energy of the normal sensor nodes denoted by NS is getting less when number of clusters increases. The reason is that when cluster region gets smaller, the distance from sensor node to cluster head gets shorter. Contrarily, when the number of cluster increases, the energy consumed in cluster heads (CH) increases. Therefore, from Fig. 3, it is observed that the energy dissipation of proposed FCA is more efficient than that of the RC scheme with the number of cluster 1 <q<20.

We assumed that the life time is time duration of WSN working until the energy of any one node runs out. With the assumption of perfect energy distribution on the nodes and the total energy of all nodes E_T= 100J, Fig. 4 thus depicts the comparison of lifetime of WSN for FCA and RC. It is obvious that the lifetime with FCA is almost more 50% to 20% than that with RC while q is increased from 1 to 5. When the number of cluster increases, the lifetime with FCA is always longer than that of RC due to the energy efficiency of normal sensor nodes.

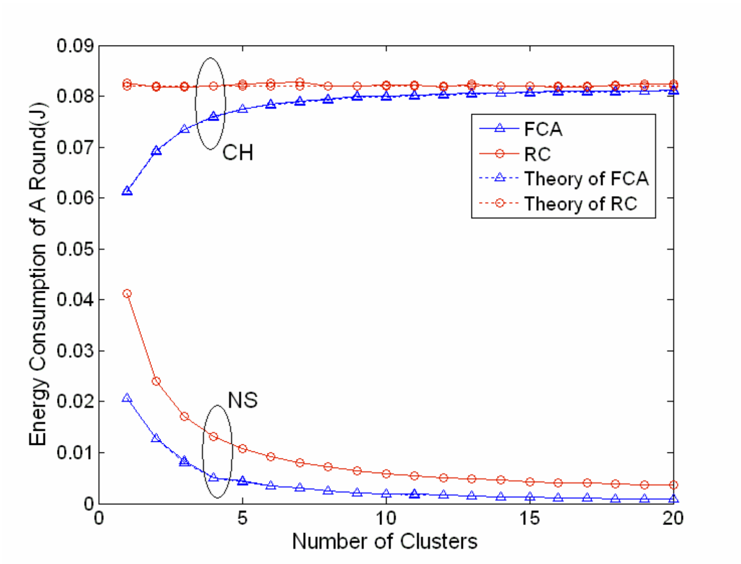

Fig. 3. Energy consummation in one round for FCA and RC

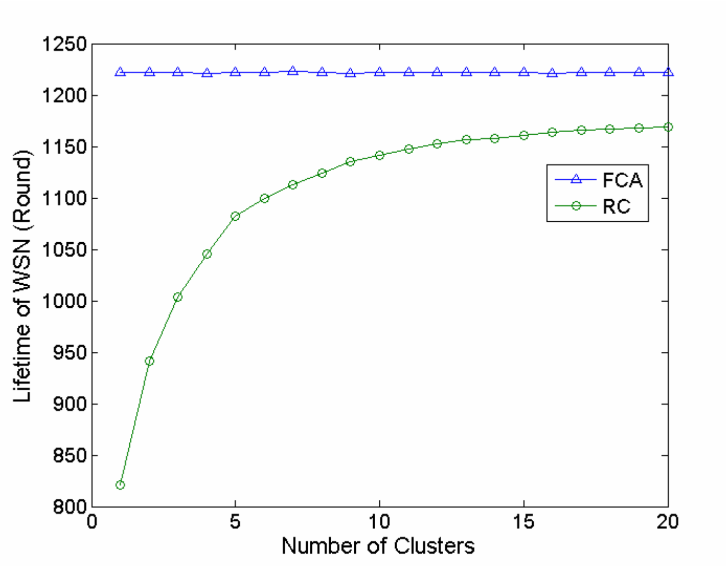

Fig. 4. Lifetime comparison of FCA and RC withop optimal energy distributed sensors

In Fig. 4, the network lifetime is evaluated based on perfect energy distribution for all sensor nodes and cluster heads. In reality, the distributed energy for every sensor node is almost the same. Moreover, when number of cluster is small (q<10), cluster head should be distributed more energy in order to send more data. Similarly, energy for all cluster heads is the same. Therefore, we distributed different energy to both sensor nodes and cluster heads to investigate the lifetime performance of a heterogeneous WSN.

To investigate the lifetime of proposed FCA with heterogeneous sensors, we distribute different total energy E_n and E_{ch} to sensor nodes and the cluster heads, respectively. Fig. 5 shows the comparison of network lifetime vs. number of clusters for FCA and RC. From Fig. 5, with the proposed FCA when the distributed energy for cluster head is higher of E_{ch} =5 E_n= 500J, the network lifetime is limited to 4500 rounds by the lifetime of sensor node with the number of cluster q = 10. Besides, when the distributed energy of cluster heads decreases to E_{ch} = 2.5E_n= 250J, the network lifetime is limited to 3000 rounds when the number of clusters is equal to 8. However, with the RC, when the number of clusters is equal to 12 the network lifetime is limited to 2000 rounds which is shorter than that of FCA.

When the distributed energy of cluster head decreases to the same as that of sensor nodes (E_{ch} = E_n= 100J), the network lifetime of FCA and RC is limited to 2000 and 1100 rounds respectively. Moreover, the optimal number of clusters q_{opt} is 5 and 8 for FCA and RC respectively. Thus, it is easily seen the tradeoff of the distributed energy of cluster heads and sensor nodes with the number of clustering in WSNs.

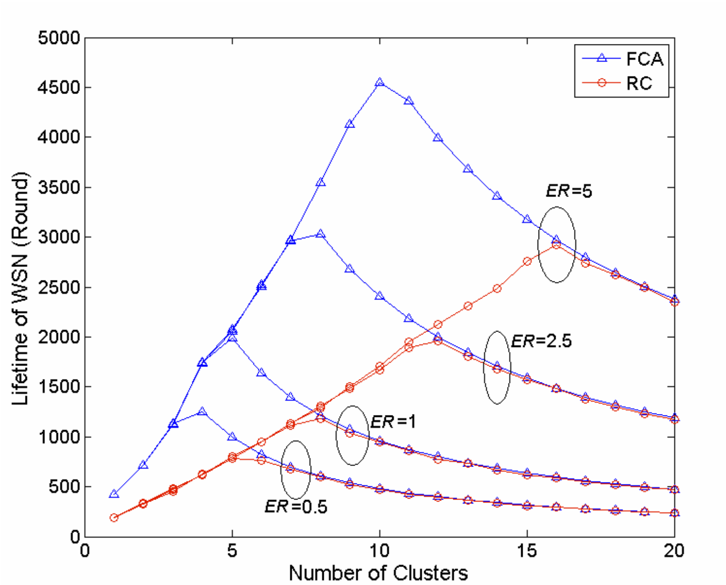

Fig. 5. The comparison of Lifetime for FCA and RC with heterogeneous sensors

Besides, the rising curve in Fig. 5 depicts the energy dissipation of sensor nodes is decreased with the increasing number of clusters. But contrarily the curve going down illustrates that the consuming energy of cluster head increases with the increasing number of clusters. To compare the energy efficiency of WSNs, we further define the energy efficiency (EE) as the ratio of total consumed energy to the network lifetime by

$$EE = \text{Lifetime}/(E_{ch} + E_n). \quad (8)$$

Moreover, the energy ratio (*ER*) of energy of cluster heads to distributed energy of cluster heads and distributed energy of sensor nodes is defined by

$$ER = E_{ch} / E_n \quad (9)$$

for the WSNs. Therefore, we can maximize the life time of WSN by deploying adequate number of clusters according to the *ER* and *EE* as shown in Table 2. From Table 2, it is obviously that the proposed FCA outperforms the RC scheme. Moreover, the FCA and RC perform the highest energy efficiency at q=5 and q=8 respectively.

Table 2. The comparison of energy efficiency and optimal number of clusters for FCA and RC with heterogeneous sensors

	ER	0.5	1	2.5	5
FCA	*EE*	8.34	9.935	8.66	7.58
	q_{opt}	4	5	8	10
RC	*EE*	5.21	5.92	5.61	4.87
	q_{opt}	5	8	12	16

5 Conclusions

In this paper, an energy efficient clustering algorithm is proposed to prolong the lifetime of cluster-based WSN. The proposed FCA gives uniform area of cluster area for the WSN and save the energy dissipation of normal senor nodes in the cluster. Simulation results show that the FCA outperforms the RC with more 80% energy efficiency and prolong the life time for both homogeneous and heterogeneous WSNs. Moreover, the FCA and RC perform the highest energy efficiency at number of clusters q=5 and q=8 respectively.

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References

1. Culler, D., Estrin, D., Srivastava, M.: Overview of Sensor Networks. IEEE Computer 37(8), 41–49 (2004)
2. Akyildiz, I.F., Su, W., Sankarasubramaniam, Y., Cayirci, E.: Wireless Sensor Network: A Survey. Computer Networks 38, 393–422 (2002)

3. Duarte-Melo, E.J., Liu, M.: Analysis of Energy Consumption and Lifetime of Heterogeneous Wireless Sensor Networks. In: Proc. of IEEE Globalcom 2002, pp. 21–25 (2002)
4. Younis, O., Fahmy, S.: HEED: a Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks. In: IEEE Trans. Mobile Computing., pp. 660–669 (2004)
5. Zhu, J., Papavassiliou, S.: On the Energy-Efficient Organization and the Lifetime of Multi-hop Sensor Networks. IEEE Commun. Letters 7(11), 537–539 (2003)
6. Raghunathan, V., Schurgers, C., Park, S., Srivastava, M.B.: Energy-Aware Wireless Microsensor Networks. IEEE Signal Processing Magazine 19(2), 40–50 (2002)
7. Schurgers, C., Srivastava, M.B.: Energy Efficient Routing in Wireless Sensor Networks. In: Proc. of IEEE Military Commun. Conf. 1, 357–361 (2001)